Biochemical Properties of Decomposing Cotton and Corn Stem and Root Residues

L. M. Zibilske* and L. A. Materon

ABSTRACT

Maintaining soil C is especially difficult in hot climates. Information is needed regarding the influence of residue biochemical properties on decomposition in hot, semiarid climates so that management practices can be developed that improve organic matter retention. Litterbags containing stalk or root tissues of senescent cotton (*Gossypium hirsutum* L.) or corn (*Zea mays* L.) were placed on the surface or 10 cm below the surface of a fallow Hidalgo sandy clay loam (fine-loamy, mixed, hyperthermic Typic Calciustoll) near Weslaco, TX, USA (26°9′ N lat., 97°57′ W long.), and were monitored quarterly for 1 yr for changes in mass, water-extractable C (WEC), water- and alcohol-extractable polyphenolics (WEP and AEP, respectively). Surface-placed cotton residues retained more mass than when buried, from approximately 80% (surface) to <50% (buried). For corn, retention ranged from approximately 60 to approximately 70% for surface residues to approximately 40% for buried residues. Most mass loss occurred within the first three months. The greatest increases in WEC (approximately 1500 μg C g^{-1} for corn; approximately 500 μg C g^{-1} for cotton) and WEP (approximately 175–325 μg g^{-1}) for corn also occurred within the first 3 months. Water-extractable polyphenolics peaked (about 100 μg g^{-1}) in cotton residues at 6 mo, while corn residues reached a maximum (approximately 300 μg g^{-1}) at 3 months. Over a year, AEP decreased in cotton stem residues, from approximately 5 to 8 to approximately 2 μg g^{-1}. Surface cotton roots maintained approximately 6 μg g^{-1} after three months. Results illustrated the importance of residue moisture content during decomposition, and indicate that different residues may have different capacities to hold moisture, which may affect the biochemical characteristics and kinetics of decomposition.

Soil organic matter (SOM) content is an important factor in the long-term sustainability of agricultural production systems. Many agricultural practices, such as intensive tillage and crop residue removal, promote soil C loss. Reduced tillage (Bayer et al., 2001; Zibilske et al., 2002) and the conservation of crop residues often slow or reverse C losses compared with conventional agronomic practices (Kern and Johnson, 1993). Conservation tillage maintains crop residues on the soil surface, reduces soil mixing and stratifies SOM inputs and consequent nutrient mineralization (Unger, 1991) and SOM accumulation (Blevins et al., 1984). Residues on the soil surface decompose more slowly than buried residues (Douglas et al., 1980) due in part to greater exposure to extremes in moisture availability compared with buried residues (Franzluebbers et al., 1994; Rovira and Vallejo, 2002).

Soil C decomposition and retention also depend on residue biochemical quality (Melillo et al., 1982; Heal et al., 1997; Seneviratne, 2000), soil factors (Alvarez and Lavado, 1998; Bayer et al., 2001) and on the environmental conditions (Meentemeyer, 1978) under which the residues are decomposed by microorganisms. Both residue placement and quality contribute to stratification and accumulation of C and nutrients in reduced-tillage soils.

Relatively little is understood about relative C inputs to soil from roots and shoots (Gale and Cambardella, 2000), and little is known specifically about the contribution of roots to soil C (Soon and Arshad, 2002). Preserving crop residues where they are physically produced (i.e., shoots above ground, roots below ground) further differentiates inputs based on residue quality compared with the mixing of residues and soil during tillage.

Roots dominate organic matter inputs to the upper soil horizons while aboveground residues provide the surface inputs in no-till systems. Carbon inputs from roots can be substantially different from that of shoots (Puget and Drinkwater, 2001) resulting in different decomposition and nutrient mineralization patterns. Gale and Cambardella (2000) concluded that root-derived C was more responsible than surface residue-derived C for soil C gains in a no-till soil. The influence of roots on SOM transformations may be greater than that of aboveground residues (Milchunas et al., 1985; Norby and Cotrufo, 1998).

Plant polyphenolics are important factors in C and N transformations and nutrient fluxes in soil (Palm and Sanchez, 1990; Martens, 2002), and play an important role in aggregate stability (Martens, 2002). Residues high in lignin and polyphenols tend to extend C residence time in soils (Tian et al., 1993). Using crop residues high in polyphenolic content may encourage C retention (Tian and Brussard, 1997) and counteract the more rapid SOM losses in tropical climates (Sanchez and Logan, 1992; Shang and Tiessen, 1998; Jenkinson and Anayaba, 1977).

Soil pH has been found an important factor in the solubility of phenolic acids (Whitehead et al., 1983). Whitehead et al. (1981) found that water-extractability of phenolic acids increased with increasing pH, with the solubility threshold between pH 7.5 and 10.5. However, in a review of N release patterns from a broad range of plant litters and leaves in tropical systems, Seneviratne (2000) found that all of the reviewed studies were conducted in soils with pH ranges from 4.5 to 6.5. This indicates a lack of information regarding the relationships

L.M. Zibilske, USDA-ARS, Integrated Farming and Natural Resources Research Unit, 2413 E. Hwy 83, Weslaco, TX 78596-8344. L.A. Materon, The Univ. of Texas-Pan American, Biology Dep., 1202 West University Drive, Edinburg, TX 78539. Mention of trade names or commercial products in this article is solely for providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. Received 16 Feb. 2004. *Corresponding author (lzibilske@weslaco.ars.usda.gov).

Published in Soil Sci. Soc. Am. J. 69:378–386 (2005).

677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: AEP, alcohol-extractable polyphenolics; DOM, dissolved organic matter; SOM, soil organic matter; WEC, water-extractable organic C; WEP, water-extractable polyphenolics; *, significant at the 0.05 probability level; **, significant at the 0.01 probability level; ***, significant at the 0.001 probability level.

between residue phenolics and humification processes in alkaline soils.

Decomposition models developed for cooler climates have met with limited success when applied to tropical systems (Gijsman et al., 1997). This may be due in part to differences in C cycling and nutrient transformations in the warmer systems. The combination of warmer climate and alkaline soils constitutes a unique agricultural system producing cotton, sorghum [*Sorghum bicolor* (L.) Moench], corn, vegetables, and citrus. Much more information concerning C retention and nutrient cycling is needed to ensure long-term productivity of these systems.

The objective of this research is to test the hypothesis that plant tissue type (stems and roots), key chemical components of plant tissues (polyphenolics, soluble C) and placement (surface or buried at 10 cm) affect the kinetics of SOM loss in hot climates.

MATERIALS AND METHODS

Senesced stems and roots of cotton and corn were collected in August 2002 from plow-till managed plots at the USDA research farm in Weslaco, TX (26°9′ N lat. 97°57′ W long.) in a semiarid, subtropical zone. The crops had been grown on the same soil (Hidalgo sandy clay loam) on which the present experiment was conducted. Crop fertilization and pest control measures used were those commonly practiced in the region. Corn and cotton residues were brushed gently, oven-dried (65°C), and ground to pass a 0.5-mm sieve. Samples were analyzed for total C and N using dry combustion (Elementar VarioMax CN analyzer, Elementar Americas, Inc. Mt. Laurel, NJ). Cotton stems contained 0.41 g C g tissue^{-1} and 0.0088 g N g tissue^{-1} (C/N = 46.6). Cotton roots contained 0.40 g C g tissue^{-1} and 0.0098 g N g tissue^{-1} (C/N = 40.8). Corn stems contained 0.43 g C g tissue^{-1} and 0.011 g N g tissue^{-1} (C/N = 39.1). Corn roots contained 0.43 g C g tissue^{-1} and 0.016 g N g tissue^{-1} (C/N = 26.9). Selected soil properties are: sand, 522 g kg^{-1}; silt, 210 g kg^{-1}; clay, 267 g kg^{-1}; pH (water), 7.8; organic C, 12.4 g kg^{-1}; organic N, 0.92 g kg^{-1}; P (bicarbonate extractable), 5.7 mg kg^{-1}. The experiment was conducted from August 2002 through July 2003. Air temperatures, soil temperatures, and precipitation events were continuously recorded at a weather station located approximately 30 m from the experimental site.

Roots were excavated by shovel, collecting roots within a radius of 20 cm from the standing stalk stub and between 10 and 20 cm deep. Plant parts were brushed gently to remove most adhering soil and were cut to 10-cm lengths. Corn stem sections ranged from 25- to 33-mm diam., corn roots from 3 to 7 mm; diameter of cotton stem sections ranged from 15 to 20 mm, and roots from 3 to 5 mm. Only cotton root laterals were used. Nylon mesh bags (15-cm square with 1.0-mm openings) were prepared and 20 g of air-dried plant material were placed into separate bags. The bags were sewn shut with nylon thread. Care was taken to leave enough room in the filled bags so that when compressed by the soil, the bags would collapse around the plant matter, increasing the contact between soil and plant residues.

Bags were placed within the experimental plot (10 by 10 m) in a completely randomized design with four replications of tissue and placement. The bags and were horizontally separated by 20 cm. A location was chosen for the placement of litterbags adjacent to the plots on which the crops were grown. The site was fallowed in the spring of the year and kept weed-free with glyphosate [N-(phosphonomethyl) glycine] sprays as needed until bag placement in August 2002.

A trowel was used to excavate soil to 10 cm and bags were placed horizontally into the holes and covered with soil. Identification tags were attached with thread to the bags such that the tag remained above the surface of the soil when the bags were covered. For surface placement, bags were secured to the soil surface by a thread attached at each bag corner to rigid aluminum wires pressed into the soil. This effectively pressed the bags against the soil surface.

Four replicate bags of each plant material and soil placement combination were collected after 0, 3, 6, 9, and 12 mo. The bags were opened in the laboratory, the contents removed and gently brushed to remove adhering soil. This process removed all but a small amount of soil (53–115 mg bag^{-1}, data not shown). Brushed plant materials were used in all analyses. Subsamples were used to determine the oven-dry (65°C for 3 d) mass remaining. Field-moist material was used for all biochemical tests with the exception of AEP, which was oven dried (65°C) and ground (0.5-mm screen) before extraction. Soil samples were taken near the buried bag position to determine soil moisture content at the sampling times.

Data reported here derive directly from plant material instead of surrounding soil and, therefore, relate more to the narrower subject of plant material decomposition than to broader topics of soluble C effects in soil. The term, WEC will be used instead of dissolved organic matter (DOM) for this discussion. The method used to generate the samples probably removed colloidal C as well as dissolved C; therefore WEC may be a more accurate description in the context of the current experiment. Water-extractable C in plant tissues was determined by mechanically shaking 5 g of plant material in 50 mL of deionized water for 30 min. in a conical centrifuge tube. Tubes were centrifuged at 250 × *g*, membrane-filtered (0.45 μm), and the liquid was either analyzed immediately or frozen (−20°C) until analysis. The extracts were analyzed for total organic C with a Dohrmann DC-190 Total Organic Carbon Analyzer (Tekmar-Dohrmann, Rosemount Analytical, Inc., Santa Clara, CA).

Water-extractable polyphenolic compounds were determined in the extracts by colorimetric reaction with Folin-Denis reagent (King and Heath 1967) using an aqueous tannic acid standard line. For AEP, plant tissue was milled to 0.5 mm and 100 mg was extracted three times with 20 mL of 50% (v/v) aqueous methanol at 75°C for 1 h (Osono and Takeda 1999). Polyphenolics were quantified with Folin-Denis reagent as described above. The standard curve was prepared with tannic acid.

Data were analyzed by repeated measures ANOVA (Systat 8.0, Systat Software, Inc., Point Richmond, CA). The Pearson correlation matrix was calculated on the dataset, along with Bonferroni probabilities for multiple comparisons. Bonferroni probabilities are reported as *, **, and *** to denote significance at the 0.05, 0.01, and 0.001 levels, respectively. Standard errors were calculated using the appropriate error terms.

RESULTS AND DISCUSSION

Weather Data

Climatic data collected at the site weather station (30 m from the plots) included minimum-maximum air temperatures, soil temperature (10 cm), and precipitation. Rainfall and temperatures (10-d means) during the experiment were somewhat atypical for this subtropical

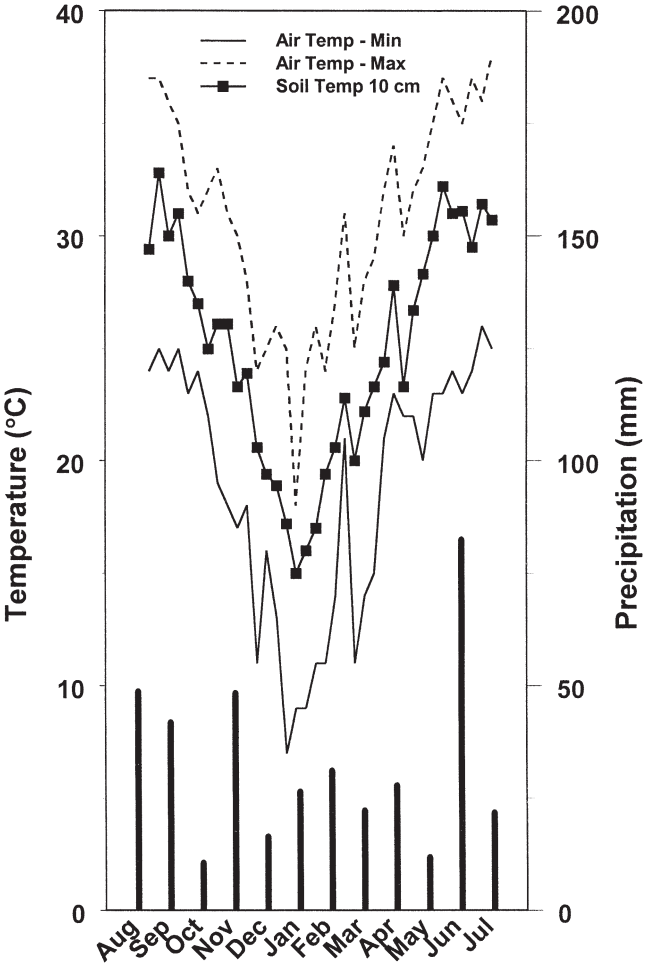

Fig. 1. Soil and air temperatures summarized for the 1-yr field incubation of plant tissues. Bars at the bottom are precipitation.

semiarid location (Fig. 1). Most rain usually occurs from October through March. In the experiment year, rainfall was more uniformly distributed, although the total amounted to only 391 mm. Locally maintained weather records (not shown) indicate that annual rainfall in the past 5 yr has been lower than normal, which averages 500 mm. Lowest temperatures in air (7°C) and soil (15°C) occurred during December-January. The soil does not freeze at this location.

Mass Loss

Loss of tissue mass was generally most rapid for buried tissues during the first three months of the experiment (Fig. 2). Mass loss was more rapid for buried residues than for surface residues during the first 6 mo. Greater mass loss rates for buried than surface residues have been previously reported (Douglas et al., 1980).

Corn and cotton stems and cotton roots displayed similar mass losses at all times. Corn stem (Fig. 2a) and cotton stem (Fig. 2c) losses were slow, relative to buried residues, and were near linear for the entire experiment. At three months, all surface residues retained a significantly greater ($P = 0.031$) portion of their initial mass than corresponding buried tissues. Residue mass remaining was significantly greater for corn stems ($P = 0.011$), cotton stems ($P = 0.008$), and cotton roots ($P = 0.022$) during the remainder of the experiment. Corn root decomposition (Fig. 2b) was very different from the other residues. Buried corn root mass loss was nearly linear for 6 mo, but both surface and buried roots lost very little mass afterwards. Surface corn stems lost >30% of their initial mass, where cotton lost only half that amount. Interestingly, buried corn (Fig. 2a), cotton stems (Fig. 2c), and cotton roots (Fig. 2d) lost similar amounts of mass during the experiment. After 6 mo, corn root placement (Fig. 2b) appeared to have no effect on mass loss, although at 12 mo, surface residues retained significantly higher ($P = 0.037$) mass than the corresponding buried tissue.

Differences in mass loss rates can be partly attributed to differences in environmental conditions between the soil surface and 10 cm beneath the surface. Surface residues are more exposed to extremes of wetting and drying that can modify the kinetics of decomposition (Franzluebbers et al., 1994). Seneviratne and Wild (1985) found that mild wet/dry cycles could enhance CO_2 emission from soil, suggesting that variation in environmental conditions affects decomposition rates.

Generally, more than 75% of residues remained after 1 yr when placed on the surface, compared with near 40% when the residues were buried. This supports the conclusions of Douglas et al. (1980) that surface residues decompose less rapidly than buried residues. Evaluated over the year, plant tissue type and placement were strong predictors for mass loss (Table 1). First-order rate constants calculated with mass loss data (Table 2) that quantify the relationships are shown in Fig. 2. Differences between surface-placed and buried residues, as well as between the four plant tissues evaluated in the experiment support the finding that tissue type and placement strongly affect decomposition.

Another factor that may affect decomposition rates is the amount of contact between soil and the residue (Henriksen and Breland, 2002). Since litterbags often reduce that contact, they can affect experimental results. Tian et al. (1992) reported that rates of nutrient release were proportional to mesh size of the litterbag used. The chemical quality of residues strongly affects mass loss, with more readily degraded substrates being less affected by reduced soil contact (Breland, 1994). Poor soil contact was also found to slow straw decomposition (Christensen, 1986). Use of litterbags in the current study undoubtedly affected the rates of decomposition, but was considered a fixed effect for treatment comparisons.

Water-Extractable Carbon

The roles of DOM in soil systems are complex (Zsolnay, 2003) and include its use as an energy source for decomposition of other substrates (Reinertsen et al., 1984), and for use by other microbes not located near organic substrates (Zsolnay and Görlitz, 1994). The transient nature of DOM in soil suggests that it may be more useful for evaluating current biological activities.

Concentrations of WEC (Fig. 3) were generally greater

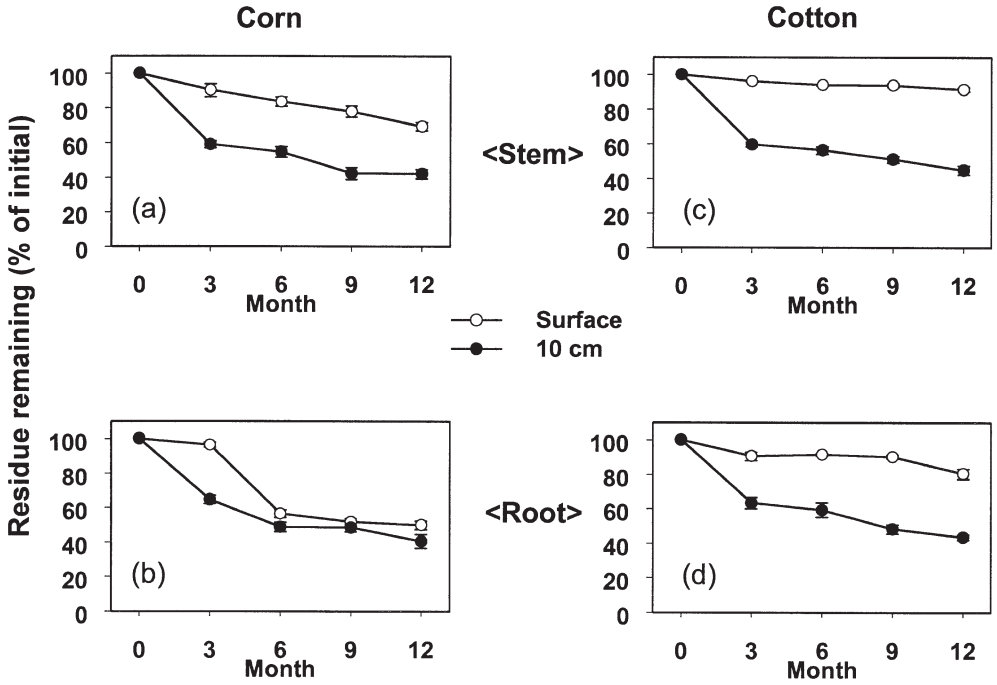

Fig. 2. Corn and cotton dry matter remaining after field incubation for 1 yr. Bars = S.E.M., $n = 4$.

than those reported in the literature for whole soil. Zsolnay and Görlitz (1994) found a mean of 9.4 μg WEC g soil^{-1} for intensively used agricultural soils. Wang et al. (2003) found WEC from 23 soils to average 294 μg WEC g soil^{-1}. The difference is undoubtedly due to extracting plant material directly, instead of extracting from soil. Beginning levels of soluble C were very low since whole residues were extracted to evaluate a more realistic situation in the field. Significant increases were detected in WEC concentrations after the first three months of field exposure for all treatments (Fig. 3). At the end of the experiment, WEC in all treatments was greater than at the beginning, indicating that polymer hydrolysis was still a prominent activity. The purpose of monitoring WEC was not to quantitatively determine the rates of release from decomposing tissue, but to correlate WEC to other measures of decomposition, since it has been proposed that DOM (WEC) may be the principal C source for soil microbes (Marschner and Kalbitz, 2003).

Cotton residues (Fig. 3c,d) yielded generally lower amounts of WEC than corn. At three months, cotton stems contained significantly greater ($P = 0.013$) WEC than roots, and continued to be greater at 6 mo ($P = 0.026$) and 9 mo ($P = 0.041$). The reason for the significant decrease ($P = 0.019$) at 12 mo for cotton stem (Fig. 3c) is unknown. Other parameters at that time did not show the same sharp decrease as WEC. Over the course of the experiment, only placement and time were significant influences on WEC content in cotton (Table 1). While data on cotton are sparse, Reinertsen et al. (1984) attributed early decomposition rates of residue (wheat straw in sand) to soluble C and a meta-available C fraction in the soil. Our results for cotton suggest a low, but more stable level of WEC persists throughout the incubation. WEC levels after three months may have been stabilized by tissue polyphenolics in this incubation.

Corn residue WEC (Fig. 3a,b) also increased in the first three months. Surface-placed stems contained significantly

Table 1. Probability values from the ANOVA procedure for the treatment variables. Tissue = stem or root; Position = surface-placed or buried.

Source	% Remaining†	WEC‡	WEP§	AEP¶
		Cotton		
Tissue	0.019	0.964	0.009	0.018
Position	<0.001	0.120	0.014	0.313
Tissue × position	0.004	0.918	0.967	0.023
Time (tissue)	0.001	0.001	<0.001	<0.001
Position × time (tissue)	0.003	0.590	0.002	0.004
		Corn		
Tissue	<0.001	0.948	0.128	0.254
Position	<0.001	0.309	<0.001	0.036
Tissue × position	<0.001	0.012	<0.001	0.045
Time (tissue)	<0.001	0.002	<0.001	0.010
Position × time (tissue)	<0.001	0.506	<0.001	<0.001

† Remainder of original 20 g of plant mass, %.
‡ Water-extractable C.
§ Water-extractable polyphenolics.
¶ Alcohol-extractable polyphenolics.

Table 2. First-order rate constants for 1-yr decomposition of surface-placed and buried cotton and corn stems and roots.

Tissue	Placement	k	R^2
		(3 mo)$^{-1}$	
	Cotton		
Stem	Surface	−0.069	0.993
	Buried	−0.094	0.873
Root	Surface	−0.015	0.804
	Buried	−0.075	0.900
	Corn		
Stem	Surface	−0.029	0.993
	Buried	−0.054	0.873
Root	Surface	−0.071	0.864
	Buried	−0.084	0.901

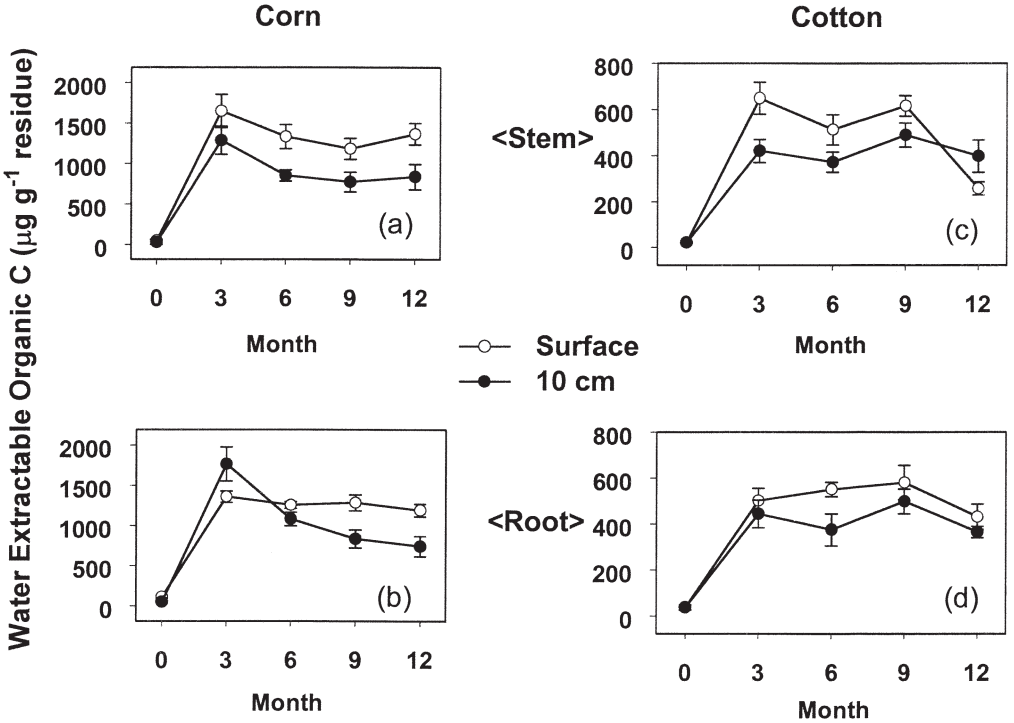

Fig. 3. Water extractable organic C (WEC) in plant residues during a 1-yr field incubation. Bars = S.E.M., n = 4.

higher amounts than buried stems (Fig. 3a) at 6 mo (P = 0.029), 9 mo (P = 0.038), and 12 mo (P = 0.022). At three months, surface-placed roots contained significantly more (P = 0.033) WEC than buried roots (Fig. 3b). However, the effect was not maintained as root WEC content fell significantly below stem content at 9 mo (P = 0.027) and 12 mo (P = 0.017). Evaluated over the entire experiment, placement and time were the only significant influences on corn WEC content (Table 1).

Water-Extractable and Alcohol-Extractable (Tissue) Polyphenols

Multiple roles for polyphenolic compounds in soil processes have been documented. Polyphenolic binding of protein can lead to N immobilization (Tian et al., 2001), which can slow decomposition and promote SOM accumulation. In addition, polyphenolics affect other nutrient transformations in soil (Hättenschwiler and Vitousek, 2000), and contribute directly to humus formation by reacting with microbially produced molecules (Martens, 2000), forming stable macromolecules. Whitehead et al. (1983) found water-soluble forms of phenolic acids were <0.7% of the total extracted with 2 M NaOH. In another study (Whitehead et al., 1981) water-extractability of phenolic acids was found to increase with increasing pH, with the solubility threshold between pH 7.5 and 10.5. This suggests that WEP in the present experiment may have been reduced by soil pH.

Corn tissues (Fig. 4a,b) generally released more than twice the polyphenolics than cotton tissues (Fig. 4c,d) during decomposition. Corn stems and roots released most of the polyphenolics within the first three months of the experiment. At three months, significantly greater (P = 0.003) WEP was found in surface-placed corn stems than in buried (Fig. 4a). The effect was maintained for all following sampling times. For roots, however, a significant increase (P = 0.044) in WEC was present only at three months for surface-placement compared with buried roots (Fig. 4b). Water-extractable polyphenolics were higher in surface residues compared with buried residues (Fig. 4a,c) between 3 and 12 mo, except for the last observations on cotton roots (Fig. 4d). Evaluated over the 1-yr period, cotton tissue, tissue placement, and time significantly affected WEP (Table 1). For corn, however, tissue type did not affect WEP, but position did have a significant effect. This indicates that there may be significant differences between cotton and corn that result in differential decomposition dynamics.

Since polyphenolic compounds are good indices of residue quality (Constantinides and Fownes, 1994), cultivation of crops that produce residues high in polyphenolics has been proposed for tropical agricultural systems that would slow SOM decomposition and contribute to SOM accumulation (Tian and Brussard, 1997). Initial content of N, polyphenolic compounds, and lignin are primary factors in determining C and N mineralization from residues (Constantinides and Fownes, 1994). In general, the higher the polyphenolic content of the residue, the slower the decomposition (Tian et al., 2001). The protein binding capacity of polyphenols slows N availability in soil (Cadisch et al., 1998; Tian et al., 2001).

Different methods are commonly used for determining plant polyphenolic content, which makes direct comparisons of results from this study with others more difficult. Most reported data concerning polyphenolics were determined for fresh plant tissue. This is important because plant polyphenolics can change substantially in chemical composition and effects during senescence (Hättenschwiler and Vitousek, 2000).

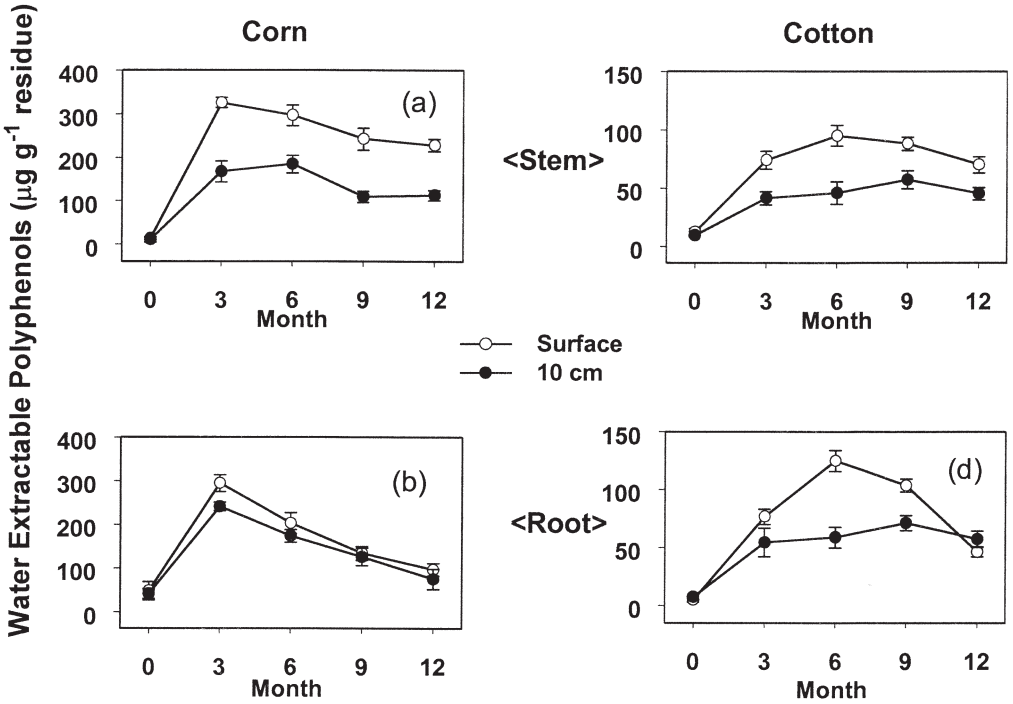

Fig. 4. Water extractable polyphenolics (WEP) in plant residues during a 1-yr field incubation. Bars = S.E.M., n = 4.

Corn stem polyphenolic (AEP) concentration trended slightly upward during the first three months, regardless of placement (Fig. 5a). Surface-placed stems were significantly greater (P = 0.034) in AEP than buried stems only at 12 mo. For corn roots (Fig. 5b), AEP in buried tissue was significantly decreased (P = 0.026) at three months. This significant difference was maintained for the duration of the experiment. This was the only corn tissue-placement combination that showed appreciable net change in concentration in polyphenolics during the experiment.

Alcohol-extractable polyphenolics in cotton residues (Fig. 5c,d) decreased significantly during the first three months of incubation. Cotton stem polyphenolic concentration was stable and similar between surface-placed and buried stems after three months (Fig. 5c). After the initial decline, cotton roots (Fig. 5d) showed marked differences in polyphenolic content. Surface-placed roots changed

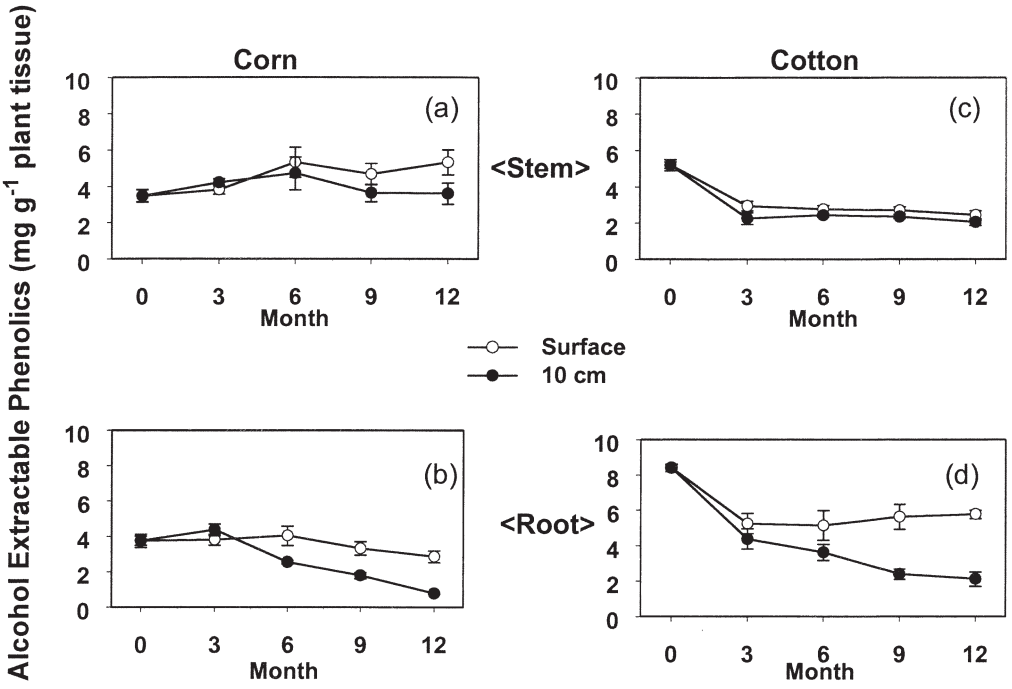

Fig. 5. Alcohol extractable polyphenolics (AEP) in plant residues during a 1-yr field incubation. Bars = S.E.M., n = 4.

little from the three-month level for the remainder of the experiment, but buried roots continued a slow decline that became significantly lower ($P = 0.046$) than surface-placed roots at 6 mo, and further separated for the remainder of the experiment.

These results indicate greater initial polyphenolic content in cotton residues, which might have been expected to slow mass loss of cotton tissues. However, buried corn and cotton tissues appeared similar in the pattern of mass loss (Fig. 2). The greater amount of polyphenolics in cotton apparently may not have been a limiting effect on decomposition. Since no fertilizer was added to the soil or residues, N availability for residue decomposition may have been more limiting. Further work is needed to determine the relative effects of N availability and polyphenolic content of residues. Evaluated over the 1-yr period, position significantly affected AEP, and interactions between time, position and tissue were determined (Table 1). This supports the marked differences in AEP dynamics between cotton stems and roots (Fig. 5c,d, respectively).

Synthesis

For buried corn stems and roots, the highest rates of mass loss occurred during the first three months of decomposition (Fig. 2a,b). Stem mass loss was significantly correlated to WEC, whether surface-placed or buried ($r = -0.62^*$ and -0.74^*, respectively, Fig. 3a,b) for the whole year. This indicates, not surprisingly, a correspondence between decomposition rate and C released from stems during decomposition. During the same period, large increases in WEP were seen for both corn stems and roots (Fig. 4a,b) of which only the buried placement was significantly correlated ($r = -0.69^*$) to mass loss. Water-extractable C and WEP were strongly correlated for corn stems and roots, with correlation coefficients ranging from 0.98^{***} to 0.70^* for surface and buried placements, respectively. This suggests that C compounds released from tissues originated in multiple pools of compounds in the tissues. The desiccation of surface residues, regardless of tissue type, has undoubtedly affected the decomposition characteristics of the residues.

Little change in corn tissue polyphenolics during the first three months was noted for either stem or root tissues, regardless of residue placement. Corn polyphenolics were significantly correlated only to WEP, with coefficients ranging from 0.84^* to 0.69^* for the entire incubation. Correlations tended to be negative between mass loss and tissue polyphenolics, but the relationship was not as strong ($r = -0.44$ to -0.37, corn stem and root, respectively) as was the relationship to WEP. This is probably due in part to the large pool of polyphenols contained in these tissues that changed little, except for buried roots (Fig. 5b) during the incubation.

Table 3. Tissue moisture content (% of dry wt.).

Tissue/placement		Sampling time			
		3 mo	6 mo	9 mo	12 mo
Cotton stems	surface	13.9 (4.3)†	17.9 (3.8)	7.8 (6.5)	13.4 (7.9)
	buried	77.4 (14.7)	36.3 (7.5)	30.2 (11.3)	33.1 (6.3)
Cotton roots	surface	8.2 (8.1)	5.1 (2.4)	24.7 (14.7)	12.0 (10.6)
	buried	69.5 (15.4)	48.2 (9.4)	41.3 (7.7)	26.8 (8.8)
Corn stems	surface	8.0 (1.8)	4.9 (2.9)	19.5 (7.2)	5.6 (11.4)
	buried	35.4 (7.8)	20.9 (5.5)	45.9 (9.8)	29.0 (12.5)
Corn roots	surface	5.4 (7.9)	6.1 (8.3)	17.6 (12.8)	4.5 (5.6)
	buried	24.8 (6.2)	30.9 (4.6)	29.0 (9.7)	15.1 (4.4)

† Numbers in parentheses are standard deviation ($n = 4$).

Cotton mass loss was negatively correlated to WEC for buried stems ($r = -0.95^{***}$) and roots ($r = -0.88^{**}$), but was insignificantly correlated to surface-placed cotton stems ($r = -0.42$) or roots ($r = -0.51$). Not surprisingly, the relatively unfavorable conditions of the soil surface appear to contribute more to residue retention than to decomposition. Cotton stem mass loss was also correlated to WEP for both surface-placed ($r = -0.79^*$) and buried ($r = -0.94^{**}$) tissues. Root mass loss, however, correlated with WEP only when they were buried ($r = -0.91^{**}$). This might be explained by a different capacity of stem and root tissues to absorb and retain water. Accordingly, it would appear that stem tissue absorbs or retains more water than root tissue. Moreover, point-in-time measurements of biological and biochemical properties are likely to be strongly affected by the amount of moisture available to the decomposing microbes around the time of sampling. Table 3 shows the content of water in the residues sampled over the experimental period. Expectedly large differences in surface-placed versus buried residue moisture content were observed. Surface-placed stem residues never contained more than about 20% moisture, while buried residues contained from a low of about 15% to a high of about 77% moisture. Interestingly, cotton roots contained more moisture than corn roots under the same environmental conditions. Plant residue moisture content was correlated to several indices. Buried corn stem WEC and mass loss correlated well to plant tissue water content (0.68^{**}, -0.79^{**}, respectively). Neither surface nor buried placements of corn roots correlated to tissue water contents. For cotton, surface-placed stem mass loss was correlated to tissue water content (-0.71^*) and to WEP (0.83^{**}). Buried stems showed no response, indicating that subsurface soil moisture was probably not limiting the tissue properties measured. For cotton roots, tissue moisture was correlated only to WEC (0.75^*) for the surface-placement treatment. No buried cotton root parameter was significantly correlated to tissue water content, again indicating that moisture was apparently not limiting the decomposition.

Litter pieces remain on the soil surface or are turned under during a minimum tillage operation. Monitoring tissue properties of these residues rather than soil properties around the litter may be more indicative of the early stages of decomposition than whole soil parameters.

CONCLUSIONS

Management of crop residues and the biochemical quality of those residues are important factors in understanding of C dynamics in agricultural systems. Our results indicate that most residue mass is lost during the first three months of initial exposure and surface residues lost less mass than buried residues.

For cotton, residue remaining was negatively corre-

lated to WEC in the tissues, indicating not only the link between solubilization of C polymers and decomposition, but that diffusion of soluble C away from these residues and into the soil may not be rapid, thus creating a gradient. Residue remaining was also negatively correlated to WEP and AEP polyphenolics in the remaining residues. However, since WEC and WEP were generally positively correlated, a clear role for soluble polyphenolics in controlling decomposition is not apparent.

Results for corn were generally similar to those for cotton. Again, most mass loss occurred within the first three months of the incubation. Residue remaining was negatively correlated to WEC and to WEP, but direct correlations between WEC, WEP, and AEP make it difficult to resolve a role of polyphenolics for depolymerization in this system.

These results emphasize the importance of residue moisture content during decomposition, and indicate that different residues may have different capacities to hold moisture that may affect the biochemical characteristics and kinetics of decomposition.

REFERENCES

Alvarez, R., and R.S. Lavado. 1998. Climate, organic matter and clay content relationship in the Pampa and Chaco soils, Argentina. Geoderma 83:127–141.

Bayer, C., L. Martin-Neto, J. Mielniczuk, C.N. Pillon, and L. Sangoi. 2001. Changes in soil organic matter fractions under subtropical no-till cropping systems. Soil Sci. Soc. Am. J. 65:1473–1478.

Blevins, R.L., M.S. Smith, and G.W. Thomas. 1984. Changes in soil properties under no-tillage. p. 190–230. *In* R.E. Phillips and S.H. Phillips (ed.) No-tillage agriculture: Principles and practices. Van Nostrand Reinhold, New York.

Breland, T.A. 1994. Enhanced mineralization and denitrification as a result of heterogeneous distribution of clover residues in soil. Plant Soil 166:1–12.

Cadisch, G., E. Handayanto, C. Malama, F. Seyni, and K.E. Giller. 1998. N recovery from legume prunings and priming effects are governed by the residue quality. Plant Soil 205:125–134.

Christensen, B.T. 1986. Barley straw decomposition under field conditions: Effect of placement and initial nitrogen content on weight loss and nitrogen dynamics. Soil Biol. Biochem. 18:523–529.

Constantinides, M., and J. Fownes, II. 1994. Nitrogen mineralization from leaves and litter of tropical plants: Relationship to nitrogen, lignin and soluble polyphenol concentrations. Soil Biol. Biochem. 26:49–55.

Douglas, C.L., R.R. Allmaras, P.E. Rasmussen, R.E. Ramig, and N.C. Roader. 1980. Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest. Soil Sci. Soc. Am. J. 44:833–837.

Franzluebbers, K., R.W. Weaver, A.S.R. Juo, and A.J. Franzluebbers. 1994. Carbon and nitrogen mineralization from cowpea plant parts decomposing in moist and in repeatedly dried and wetted soil. Soil Biol. Biochem. 26:1379–1387.

Gale, W.J., and C.A. Cambardella. 2000. Carbon dynamics of surface residue- and root-derived organic matter under simulated no-till. Soil Sci. Soc. Am. J. 64:190–195.

Gijsman, A.J., A. Oberson, H. Tiessen, and D.K. Friesen. 1997. Limited applicability of the CENTURY model for highly weathered tropical soils. Agron. J. 88:894–903.

Hättenschwiler, S., and P.M. Vitousek. 2000. The role of polyphenols in terrestrial ecosystem nutrient cycling. Trends Ecol. Evol. 15: 238–243.

Heal, O.W., J.M. Anderson, and M.J. Swift. 1997. Plant litter quality and decomposition: An historical overview. p. 47–66. *In* G. Cadish and K.E. Giller (ed.) Driven by nature, Plant Litter Quality and Decomposition. CAB International, Wallingford, UK.

Henriksen, T.M., and T.A. Breland. 2002. Carbon mineralization, fungal and bacterial growth, and enzyme activities as affected by contact between crop residues and soil. Biol. Fertil. Soils 35:41–48.

Jenkinson, D.S., and A. Anayaba. 1977. Decomposition of carbon-14 labeled plant material under tropical conditions. Soil Sci. Soc. Am. J. 41:912–915.

Kern, J.S., and M.G. Johnson. 1993. Conservation tillage impacts on national soil and atmosphere carbon levels. Soil Sci. Soc. Am. J. 57:200–210.

King, H.G., and G.W. Heath. 1967. The chemical analyses of small samples of leaf material and the relationship between the disappearance and composition of leaves. Pedobiologia 7:192–197.

Marschner, B., and K. Kalbitz. 2003. Controls of bioavailability and biodegradability of dissolved organic matter in soils. Geoderma 113: 211–235.

Martens, D.A. 2000. Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. Soil Biol. Biochem. 32:361–369.

Martens, D.A. 2002. Relationship between plant phenolic acids released during soil mineralization and aggregate stabilization. Soil Sci. Soc. Am. J. 66:1857–1867.

Melillo, J., J.D. Aber, and J.F. Muratore. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology 63:621–626.

Meentemeyer, V. 1978. Macroclimatic and lignin control of litter decomposition rates. Ecology 59:465–472.

Milchunas, D.G., W.K. Lauenroth, J.S. Singh, and C.V. Cole. 1985. Root turnover and production by 14C dilution: Implications of carbon partitioning in plants. Plant Soil 88:353–365.

Norby, R.J., and M.F. Cotrufo. 1998. A question of litter quality. Nature (London) 396:17–18.

Osono, T., and H. Takeda. 1999. Decomposing ability of interior and surface fungal colonizers of beech leaves with reference to lignin decomposition. Eur. J. Soil Biol. 35:51–56.

Palm, C.A., and P.A. Sanchez. 1990. Decomposition and nutrient release patterns of the leaves of three tropical legumes. Biotropica 22:330–338.

Puget, P., and L.E. Drinkwater. 2001. Short-term dynamics of root- and shoot-derived carbon from a leguminous green manure. Soil Sci. Soc. Am. J. 65:771–779.

Reinertsen, S.A., L.F. Elliott, V.L. Cochran, and G.S. Campbell. 1984. Role of available carbon and nitrogen in determining the rate of wheat straw decomposition. Soil Biol. Biochem. 16:459–464.

Rovira, P., and V.R. Vallejo. 2002. Labile and recalcitrant pools of carbon and nitrogen in organic matter decomposing at different depths in soil: An acid hydrolysis. Geoderma 107:109–141.

Sanchez, P.A., and T.J. Logan. 1992. Myths and science about the chemistry and fertility of soils in the tropics. p. 35–46. *In* R. Lal and P.A. Sanchez (ed.) Myths and science of soil in the tropics. SSSA Spec. Pub. 29. SSSA, Madison, WI.

Seneviratne, G., and A. Wild. 1985. Effect of mild drying on the mineralization of soil nitrogen. Plant Soil 84:175–179.

Seneviratne, G. 2000. Litter quality and nitrogen release in tropical agriculture: A synthesis. Biol. Fertil. Soils 31:60–64.

Shang, C., and H. Tiessen. 1998. Organic matter stabilization in two semiarid tropical soils: Size, density, and magnetic separations. Soil Sci. Soc. Am. J. 62:1247–1257.

Soon, Y.K., and M.A. Arshad. 2002. Comparison of the decomposition and N and P mineralization of canola, pea and wheat residues. Biol. Fertil. Soils 36:10–17.

Tian, G., B.T. Kang, and L. Brussaard. 1992. Effects of chemical composition on N, Ca, and Mg release during incubation of leaves from selected agroforestry and fallow species. Biogeochemistry 15:1–17.

Tian, G., B.T. Kang, and L. Brussaard. 1993. Mulching effects of plant residues with chemically contrasting compositions on maize growth and nutrient accumulation. Plant Soil 153:179–187.

Tian, G., and L. Brussard. 1997. Mulching effect of plant residues of chemically contrasting compositions on soil organic matter content and cation exchange capacity. Commun. Soil Sci. Plant Anal. 28: 1603–1611.

Tian, G., F.K. Salako, and F. Ishida. 2001. Replenishment of C, N, and P in a degraded alfisol under humid tropical conditions: Effect of fallow species and litter polyphenols. Soil Sci. 166:614–621.

Unger, P.W. 1991. Organic matter, nutrient, and pH distribution in no- and conventional-tillage semiarid soils. Agron. J. 83:186–189.

Wang, W.J., R.C. Dalal, P.W. Moody, and C.J. Smith. 2003. Relationships of soil respiration to microbial biomass, substrate availability and clay content. Soil Biol. Biochem. 35:273–284.
Whitehead, D.C., H. Dibb, and R.D. Hartley. 1981. Extractant pH and the release of phenolic compounds from soils, plant roots and leaf litter. Soil Biol. Biochem. 13:343–348.
Whitehead, D.C., H. Dibb, and R.D. Hartley. 1983. Bound phenolic compounds in water extracts of soils, plant roots and leaf litter. Soil Biol. Biochem. 15:133–136.
Zibilske, L.M., J.M. Bradford, and J.R. Smart. 2002. Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil. Soil Tillage Res. 66:153–163.
Zsolnay, A., and H. Görlitz. 1994. Water extractable organic matter in arable soils: Effects of drought and long-term fertilization. Soil Biol. Biochem. 26:1257–1261.
Zsolnay, A. 2003. Dissolved organic matter: Artifacts, definitions, and functions. Geoderma 113:187–209.